UNITED STATES PATENT APPLICATION

For

METHOD AND APPARATUS TO PROVIDE EDGE ENHANCEMENTS AS PART OF A DEMOSAICING PROCESS

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METHOD AND APPARATUS TO PROVIDE EDGE ENHANCEMENTS AS PART OF A DEMOSAICING PROCESS

FIELD OF THE INVENTION

The present invention relates generally to image processing and image processing

5   devices. More particularly, the present invention relates to a method and apparatus to

provide edge enhancements as part of a demosaicing process.

BACKGROUND OF THE INVENTION

A common image processing device is a digital still camera (DSC). A DSC is an

image input device that typically includes a single charge-couple device (CCD) array. A

10   CCD array is an array of light detectors, which typically detects one of three monochrome

colors (e.g., red R, green G, or blue B) for each light detector location. To output a color

image, however, the DSC must provide a complete set of RGB (or CMY or YC_rC_r) tri-

stimulus values for each light detector location. Such a process is commonly referred to

as "demosaicing" in which full color at every pixel is calculated from a patchwork of

15   color filter values distributed over the captured image.

Thus, a typical image processing workflow for a current DSC is to capture an

image using the CCD array of light detectors, to convert the information from the light

detectors into digital form (i.e., raw captured image data), and to provide color to image

data by a demosaicing process, to perform a white balancing process, to perform a

20   chromatic improvement process, and finally to perform an edge enhancement process.

In the image capturing process, prior to demosaicing, a DSC arranges the colors

from the light detectors in a systematically repeating pattern as the raw captured image

data. For example, the raw captured image data can have "Bayer" pattern with

interleaved lines of "RGRGRG..." followed by lines of "GBGBGB..." At this point, the

captured image is represented as a mosaic of RGB color primaries for each light detector location in which no color can be viewed.

Demosaicing is thus the process of computing a complete set of tri-stimulus values at every CCD light detector location to provide color to the image. A number of algorithms can be used to compute the complete set of values, which typically involve nearest neighbor substitution, bi-linear interpolation, and median filtering. For example, a pixel or light detector location, which corresponds to a green detector can infer from neighboring detectors what red and blue values should be at that location where the green detector is located. Similarly, a pixel that corresponds to a red detector can infer from neighboring detectors what the green and blue values are at that location.

A limitation with the demosaicing process, which is equivalent to low-pass filtering process, is that it has some inherent side effects. For example, a low-pass filtering process attenuates the high-frequency detail or accentuates the low-frequency detail of an image. Thus, a common side effect is that it introduces chromatic fringing at the edges of sharp contrast boundaries in an image. That is, the edges of the sharp contrast boundaries have red and blue fringe artifacts. **FIG. 1** shows an image 100 having such red and blue artifacts referenced by numerals 101 and 103, respectively.

Currently, the DSC industry uses various forms of edge enhancement processes to improve an image. An edge enhancement process is used to detect edges in an image and to increase the edge detail of the image to produce a more realistic and sharper image in keeping with certain aspects of the Human Visual System (HVS). Such a process, however, compounds the problem of the red and blue fringe artifacts because the edge enhancement typically causes the magnitude of the color fringing to increase in direct proportion to the intensity of the enhancement.

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Furthermore, a disadvantage with the operation of a current DSC is that edge

enhancements occur at the end of the image processing workflow, i.e., after white

balancing and chromatic enhancement processes. White balancing is a process used to

calibrate the proportion of red, green, and blue color values so that the white color in the

5   image results in a pure white color without color casts. Chromatic enhancement is a

process used to provide a deeper or more saturated color to the color image. Both of

these processes, however, alter the raw captured image data before the edge

enhancements can take place.

Consequently, a great deal of spatial and chromatic information originally present

10   in the raw image data may have been before the edge enhancement process could have

access to the data. This may cause low color fidelity and degraded edge sharpness. For

example, as illustrated in **FIG. 1**, an exemplary image 100 is shown in which edge

enhancements are performed late in an image processing workflow in accordance with

prior art.

15   Referring to **FIG. 1**, image 100 shows a number "2," which is greatly magnified

for purposes of illustration. Blue and red pixel alternations can be noticed by reference to

numberals 101 and 103 in image 100 along the number "2." Such alternations are

commonly referred to as a "chromatic moiré." The chromatic moiré is greatly

exaggerated because edge enhancements occur late in the image data processing

20   workflow thus causing the image to have low color fidelity and degraded edge sharpness.

SUMMARY OF THE INVENTION

According to one aspect of the invention, an image processing method is disclosed in which an image is captured and edge enhancements are provided to the captured image as part of a demosaicing process.

5   Other features and advantages of the present invention will be apparent from the accompanying drawings, and from the detailed description, which follows below.

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BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention are illustrated by way of example and not intended to be limited by the figures of the accompanying drawings, in which like references indicate similar elements and in which:

5   FIG. 1 depicts an exemplary image in which edge enhancements are performed late in an image processing workflow in accordance with prior art.

FIG. 2 depicts an exemplary image processing system in which the present invention can be implemented;

FIG. 3 depicts a flow chart illustrating an image processing operation according

10   to one embodiment;

FIG. 4 depicts a flow chart illustrating post demosaicing processing according to one embodiment;

FIG. 5 depicts a flow chart illustrating a detailed operation for providing edge enhancements as part of the demosaicing process of FIG. 3 according to one

15   embodiment;

FIG. 6A depicts an exemplary schematic image based on raw data;

FIG. 6B depicts an exemplary schematic gray map image;

FIG. 6C depicts an exemplary high contrast masked edge for a mask image;

FIG. 6D depicts an exemplary image with unsharp edge enhancement;

20   FIG. 6E depicts an exemplary luminance graph of a cross-sectional view of the image of FIG. 6D;

FIG. 6F depicts an exemplary schematic image with multiplicative blending;

FIG. 6G depicts an exemplary image in which edge enhancments are provided as part of a demosaicing process;

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FIG. 7 depicts a flow chart illustrating an operation for a creating mask image from a fringe corrected image according to one embodiment;

FIG. 8A depicts an exemplary a 5 x 5 pixel pattern with the central pixel being a part of the edge of an image; and

5   FIG. 8B depicts an exemplary L*a*b* color space chart.

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DETAILED DESCRIPTION

According to the embodiments described herein, a method and apparatus are described in which an image is captured and edge enhancements are provided to the captured image as part of a demosaicing process. By providing edge enhancements as

5   part of the demosaicing process, significant improvements in color fidelity and edge sharpness are possible because the edge enhancement process has access to unaltered spatial and chromatic information contained in the raw captured image data.

FIG. 2 depicts an exemplary image processing system 200 in which the present invention can be implemented. The image processing system 200 can represent any

10   number of image processing devices such as, for example, an electronic camera, video camera, or a digital still camera (DSC), and is not intended to be limited to any particular image processing device.

Referring to **FIG. 2,** image processing system 200 includes a charge-couple device (CCD) array 210, an analog/digital (A/D) converter 220, memory storage 230,

15   processor 240, and output 250. The CCD array 210 is coupled to the A/D converter 220. The A/D converter 220 is coupled to the memory storage 230. The processor 240 and output 250 are coupled to the memory storage 230.

CCD array 210 is an image detector having an array of light detectors. The CCD array 210 is only one type of image detector that may be used, however, other alternative

20   image detectors can be used. For example, phototransistors, photodiodes, or any other form of photo capture device can be use as an image detector. CCD array 210 acquires raw image data using the array of light detectors. For one embodiment, CCD array 210 detects red R, green G, and blue B color primaries and arranges the color primaries in a repeating pattern such as, for example, a "Bayer" pattern, as "raw captured image data."

For an alternative embodiment, CCD array 210 detects cyan-magenta-yellow-green (CMYG) color primaries and arranges the color primaries in a repeating pattern as the raw captured image data.

A/D converter 220 is a processing device that converts analog signals into digital
5   signals. A/D converter 220 receives image information from the CCD array 210 as analog signals and converts them into digital signals. The digital signals representing the captured image are stored in memory storage 230 as the raw image data.

Memory storage 230 is a memory device to store data or information. Memory storage 230 can be a random access memory (RAM), flash memory, or other like memory
10   devices. For alternative embodiments, memory storage 230 can include a plurality of memory devices. Memory storage 230 stores image data or information from the CCD array 210 and A/D converter 220. Alternatively, memory storage 230 can also store instructions to be processed by processor 240 to perform image processing operations on image data. Furthermore, memory storage 230 can provide short-term and long-term
15   storage of image data for processing, display, and archival purposes.

Processor 240 is a processing device such as a high-speed microprocessor. Processor 240 can access memory storage 230 and process image data stored therein. For one embodiment, processor 240 processes raw image data stored in memory storage 230 and provides edge enhancements to the raw image data as part of a demosaicing process
20   as will be described in further detail below. Processor 240 can also store the edge enhanced image back in memory storage 230. Furthermore, processor 240 can cause the edge enhanced image to be sent to output 250 or to be further processed.

Output 250 can be a display device such as, for example, a liquid crystal display (LCD) or other like display device. Alternatively, output 250 can be another storage

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device or a data compression device. Furthermore, output 250 can be an interface to an external or remote device in which image data is displayed or provided to the external or remote device. Output 250 can also output information or data to the external or remote device by a direct connection or a network connection.

5   The image processing techniques described herein can be implemented by hardware and/or software contained within image processing system 200. For example, image processor 240 can execute code or instructions stored in a machine-readable medium, e.g., memory storage 230, to perform the operations as described in **FIGS. 3, 4, 5**, and **7**.

10   The machine-readable medium may include a mechanism that provides (i.e., stores and/or transmits) information in a form readable by a machine such a processor, computer, or a digital processing device. For example, a machine-readable medium may include a read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, or flash memory devices. The code or instructions

15 can be represented by carrier wave signals, infrared signals, digital signals, and by other like signals.

     FIG. 3 depicts a flow chart illustrating an image processing operation 300 according to one embodiment. The operation 300 illustrates combining "demosaicing" and edge enhancement in the same process.

20   For purposes of explanation, operation 300 begins at operation 310. Referring to **FIG. 3**, at operation 310, an image is captured. For example, the CCD array 210 can capture an image using an array of light detectors. The captured image can be stored in memory storage 230 as raw image data in a Bayer pattern. Alternatively, the raw image data can be captured in other patterns.

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At operation 350, edge enhancements are provided to the captured image as part of a demosaicing process. For example, processor 240 can process the raw image data stored in memory storage 230 to provide edge enhancements as part of a demosaicing process such as that explained with regards to **FIG. 5**. Alternatively, any form of edge

5 enhacnement process can be used for operation 300 such that it is performed as part of demosaicing.

By providing edge enhancements early in an image processing workflow, (i.e., as part of the demosaicing process), there can be significant improvements in color fidelity and edge sharpness because the edge enhancement process has access to unaltered spatial

10 and chromatic information contained in the raw captured image data.

FIG. 4 depicts a flow chart illustrating post demosaicing processing according to one embodiment. The following operations shown in **FIG. 4** can be performed after operation 350 of **FIG. 3**. Alternatively, the following operations can be optional.

Referring to **FIG. 4**, at operation 360, a post demosaicing process can be

15 performed. For example, processes to further improve the image and color can be performed such as white balancing or chromatic improvement. Alternatively, the demosaiced image can be compressed to be stored in memory storage 230.

At operation 370, the processed color image can be output to a user via a visual display. Alternatively, the color image can be output to a storage device for storage. The

20 color image can also be output to external and remote devices either by a direct connection or a network connection.

FIG. 5 depicts a flow chart illustrating the detailed operation 350 for providing edge enhancements as part of the demosaicing process of **FIG. 3** according to one embodiment. The operation 350 not only provides edge enhancement, but also

demosaicing. Thus, operation 350 illustrates an operation that provides edge

enhancements as part of a demosaicing process. For purposes of explanation, operation

350 begins at operation 510.

Referring to **FIG. 5**, at operation 510, a gray map (or brightness map) using the

raw captured image data (e.g., RGB data) is created. **FIG. 6A** depicts an exemplary

schematic image based on raw data. A demosaicing process may be employed to extract

a first order approximation for the R, G, and B pixel values of the raw data to create a

gray map (e.g., bi-linear interpolation). The gray map is an image composed of gray-level

brightness. **FIG. 6B** depicts an exemplary schematic gray map image. It should be noted

that attempts using a simplified luminance approximation for the gray map found in

Equation (1) below failed noticeably if chromatic edges are present.

Luminance =0.177*R +0.813*G +0.011*B [failed] (1)

Instead, a luminance based on L*a*b* is much more robust. However, it is not

required to use the full CIE L* calculation. The L*a*b* is one way to represent colors in

color space, in which L* represents brightness, and a* and b* define chromatic axes. The

luminance based on L*a*b* is used because it provides a perceptually uniform color

space. The RGB data can easily be converted to L*a*b* values for some assume image

white point.

At operation 520, the gray map image is stored. For example, the gray map image

such as that shown in **FIG. 6B** can be stored in storage memory 230.

At operation 530, a mask image is created, which is formed by detecting edges in

the gray map and providing enhancements to the edged. The edge detection/enhancement

process is discussed in further detail in **FIG. 7**. For one embodiment, the pixels of the

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mask image are different from the original image located in strong brightness gradient areas. The final "color" of each changed pixel is either a maximum or minimum form the pixels that surround it. It should be noted that any form of edge enhancement can be used in this invention. Current methods include unsharp masking, zero-crossing gradient

5   detection, chromatic discontinuity, and various kernel transforms. The use of the mask technique described here is just one embodiment of the edge enhancement process.

FIG. 6C depicts an exemplary high contrast masked edge for a mask image. For one embodiment, **FIG. 6C** may illustrate the mask image generated from **FIG. 6B**. Although no color is shown in **FIG. 6C**, the mask image can have fewer colors and more

10   smoothly varying colors than the original image. Moreover, the visibility of the textual edges is more pronounced and lacks the chromatic moiré around the slanted edges of the text. This can have the affect of providing a block-like appearance.

At operation 540, unsharp edge enhancement is performed on the mask image. That is, the block-like structured edges are smoothed by an unsharp edge enhancement

15   process, which changes the luminance level to accentuate the edge transition contrast of an image. Also, because the mask image has strong visual steps in its contour, it typically needs to be smoothed by adding a fractional part of the original demosaiced image to it. **FIG. 6D** depicts an exemplary image with an unsharp edge enhancement, and **FIG. 6E** depicts an exemplary luminance graph of a cross-sectional view of the image of **FIG. 6D**.

20   At operation 550, multiplicative blending is performed to obtain the final output. For example, a blending process based on the formula (2) below can be performed to obtain the desired output.

$$Output = Mask * (1-\alpha) + Original * \alpha \qquad (2)$$

This blending process yields the original demosaiced RGB values everywhere except where strong gradients were found. **FIG. 6F** shows an exemplary image with the multiplicative bending. The optimal value of α depends on use for the image. For example, if soft smooth edges necessary, then larger values of α are preferred.

5   Furthermore, for images with small text or fine jewelry, smaller values of α are preferred.

For one embodiment, **FIG. 6D** and **FIG. 6A** or **6B** may be blended multiplicatively to obtain the final image. **FIG. 6G** depicts an exemplary final output image in which edge enhancement was provided during a demosaicing process. By way of contrast to **FIG. 1** in which edge enhancement is performed at the end of an image

10   processing workflow, **FIG. 6G** shows significant improvement in color fidelity and edge sharpness. This is a result of performing edge enhancement as part of the demosaicing process.

FIG. 7 depicts a flow chart illustrating the detailed operation 530 of **FIG. 5** to create a mask image by performing edge detection/enhancement. The operation 530 uses

15   the knowledge of the edge location to sharpen the edges of an image in a non-linear way to produce contrast enhancement. For purposes of explanation, operation 530 begins at operation 710.

At operation 710, an NxN pixel neighborhood of a central pixel, which is part of a detected edge, is investigated. To determine the central pixel, a threshold criteria is

20   applied. For example, a threshold criteria is applied to each pixel to determine if it is involved in a significant brightness change compared to its neighbors. Exemplary values for the threshold range from 20-35 units based on an 8-bit monochrome image scale (after

the gray image has been created). Thus, once the central pixel is determined to have

passed the threshold criteria, the operation investigates the NxN pixel neighborhood.

The central pixel (each of the pixels that are determined as a part of the edges) is

examined in terms of a localized matrix or cell of pixels that surround the pixel in

5   question in a square array whose size is N pixels wide by N pixels high. Exemplary

values of N can be odd numbers, such as 3, 5, 7... to N. However, a 5 x 5 pixel is

preferred because it calculates in all the standard compass directions without

overwhelming the image processing device's performance. **FIG. 8A** illustrates

schematically a 5 x 5 pixel with the central pixel being a part of the edge of an image.

10   At operation 720, each of the twenty-four pixels in the neighborhood of the

central pixel is ranked based on its brightness and perceptual color values. To rank each

pixel, $L*a*b*$ values are used. The $L*a*b*$ values can be converted from RGB values

mathematically.

FIG. 8B shows an $L*a*b*$ color space chart divided into multiple bins to classify

15   the color values for each pixel. For one embodiment, the chart is divided into eight bin

spaces, but the chart can be divided more than eight bins for greater accuracy. The $a*$

axis runs from green $(+a*)$ to magenta $(-a*)$, and the $b*$ axis runs from yellow $(+b*)$ to

blue $(-b*)$.

The chart is further divided into two regions - a first region, which is anywhere in

20   between +4 units and –4 units (based on 8-bit storage values for a* and b*) on either the

$a*$ or $b*$ axis (shaded region in **FIG. 8A**), and a second region that is anywhere outside of

the first region. The color values of the first region are neutral and any pixel that falls

within the first region are grouped and handled separately than any pixel that falls within

the second region. The pixels whose chromaticity (color amount) fall within the radius of

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+ or − 4 units in the a* and b* axis are basically neutral colors and are excluded from further processing in determining the chromatic content of the neighborhood around the central pixel.

At operation 730, as for the pixels that fall within in the second region, each of the twenty-four pixels is determined to be in first and second most popular color groups. This determination is based within the eight bin spaces according to its $a*,b*$ value.

At operation 740, the average brightness of each of first and second color groups is determined. At operation 750, a test is applied to compare the central pixel brightness, which passed the threshold criteria, against the first and second popular color groups. The process checks to see if the central pixel's brightness is closer to the first most popular color group.

At operation 760, if the central pixel's brightness is closer to the first most popular color group, then the color values for the first most popular color group are stored in the RGB values of central pixel in question.

At operation 770, if the central pixel's brightness is not closer to the first most popular color group's average brightness (i.e., the central pixel's brightness is closer to the second most popular color group's average brightness), then that second most popular color group's color values are stored into the RGB value for the central pixel. However, the brightness of the central pixel is kept with its original L* value.

At operation 780, the operations 710 to 770 are repeated until all the detected edges are processed. Thus, edge detection and enhancement are provided as part of the demosaicing process.

For any neighborhood pixel that falls within the first region, it is grouped separately and handled as though they are their own separate groups. For any other pixel

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in the image that is not involved in edges, the original first order demosaiced RGB values are used.

The final image of the above operations in **FIGS. 5** and **7** can be illustrated by image 600 of **FIG. 6G** in which edge enhancement are provided as part of a demosaicing process. By creating a mask image in the above manner, the final image can be more chromatically accurate and spatially correct because edge detection and enhancement are provided as part of the demosaicing process

Thus, a method and apparatus to provide edge enhancement during a demosaicing process have been described. In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

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